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Analysis of Alternative Energy Options for Residential Buildings

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ABSTRACT - To address the crucial state of present environment, two alternative energy scenarios are considered. Initially, energy conservation and the switch to a low carbon/no carbon fuel are studied. Next, the role of renewable energy is discussed as a suitable alternative to meet energy needs and overcome the environmental and sustainability issues. In the application part of the study, two residential buildings are chosen as case studies, Technologies are including ground source heat pump for heating and cooling, solar water heaters for heating space or hot water, and photovoltaic panels for generating electricity are designed for the case studies. Even projects under hybrid systems combined from two technologies are designed. Twelve different energy options are calculated for the two case studies. Results show that if the target is reducing CO_2 emissions, what systems are the best. Besides, photovoltaic modules are a practical technology to provide electricity, but with high maintenance cost, while the ground source heat pump is a reliable renewable technology with highest possible efficiency; however, the installation is complicated. Finally, hybrid systems are having advantages over the three renewable technology systems, while they are very costly.

Keywords: Renewable energy, solar energy, solar water heaters, PV panels, ground source heat pump, residential building, emission reduction.

I. INTRODUCTION

The world faces some critical energetic and environmental challenges. Even if humankind could unite as a modern civilized society, three critical dilemmas, energy crisis, natural resource limitation, and the environment, would remain. Resolving these issues demand smart and fast solutions from all individuals.

Humankind started the industrial age proudly by inventing different kinds of machines for transportation, farming, manufacturing and construction. Man continues to invent new machines, equipment, and instruments. Man arrogantly uses his own creations without considering the consequences. Dincer (2000) cited that humankind has created environmental problems. As the human population increases, consumption and energy needs increase, consequently contributing to increasing environmental issues are rapidly increasing, too. Over-use of resources was a stylish attitude in the 1950s. In that era, the Saskatoon Electricity Facility was built without considering any switches for turning off the lights! The problem rose in the summer, when cooling systems could not take the extra heat load by lights. Gradually, considering consumption came to engineering consideration in the designing stage. Furthermore, in the first decade of the twenty-first century, energy conservation is the most important parameter in design. It is definitely time for another revolution against the industrial revolution. This transformation is due to face the consequences of abusing resources during the last century. It is time to consider renewable energies more seriously, as a result of greenhouse gases' (GHG) effects on the environment, and a limited supply of conventional energy resources (fossil fuels) (IPCC, 2001). While replacing renewable energy with non-renewable energy, methods of reducing energy consumption should also be considered.

With respect to environmental issues regarding the inefficient use of energy, climate change, stratospheric ozone depletion, and acid rain are the most crucial dilemmas. Humankind is at the phase which is so very dependent on the modern lifestyle. Man of the new century cannot survive without his own created technology. Thus, he should come up with new practical ideas to replace the energy system. The practical solutions come from the problems. New energy systems should aim to achieve:

- better efficiency,
- better cost effectiveness,
- better environment, and
- better sustainability.

It is also expected that those options be free of political dimensions, accessible to everyone, and affordable.

2. RENEWABLE ENERGY

Dincer and Midilli (2008) state energy is the major interface between nature and humans, and is an important factor in economic development. In this regard, the United Nations obligated the energy sector to follow effective atmosphere-protection strategies to boost efficiency and transition to environmentally friendly energy systems Strong (1992). Improving efficiency directly decreases CO_2 emissions, and this can be reached by cutbacks in the use of fossil fuels and replacing them with alternative energy resources (Dincer et al., 2008). Fossil fuels are used for generating heat and power in today's world, and are an enormous danger to global sustainability and stability. The problem has a snowball effect by boosting population, combined with increased demand for technology and result in increase energy need (Dincer and Midilli, 2008). McGowan (1990) cites renewable energy sources and systems are capable of affecting the following technical, environmental, economical, and political issues:

- crucial environmental issues (green house, stratospheric ozone layer, acid rain);
- environmental disgrace;
- running down of the world's conventional energy sources; and
- boosting energy consumption in developing countries.

Hartly (1990) mentions renewable energy techniques can make marketable energy by transforming natural phenomena into practical energy.

3. EFFICIENT ENERGY USE

Solutions to humankind problems are not limited to a new energy system. Part of this solution is to modify energy consumption. This means developing new methods of using energy while not significantly changing one's lifestyle. In other words, using energy effectively should be considered seriously. Resolving the original problem is not only producing energy with natural renewable resources, but also using energy wisely. These two sides should work together to find the final solution. Smart use of energy should be applied in the buildings initially construction of the building or should be considered at renovation time.

4. ANALYSIS

To size the Photovoltaic (PV) panels, one of the most popular methods is described in the following steps (Alert Idea website, 2009):

Step 1: Find the monthly average electricity consumption from hydro bills. The value of the usage is measured in kilowatt-hours (kWh). Due to the change of seasons, the consumptions for heating and cooling systems are varied, and it is recommended to consider the annual consumptions and divide by twelve to find the average monthly consumption.

Step 2: Calculate the daily average electricity consumption. Divide the number found for the average monthly consumption used in kWh by 30, being the number of days.

Step 3: Determine the location's average peak sun hours per day. This formula finds the isolation coefficient of the area. For example, for the city of Toronto the formula reads as 1.08 $kWh/m^2/dkWh/m^2/d$ in winter.

Step 4: Calculate the system size (AC watts) to provide 100% of electricity. Divide the daily average electricity use by the average sun hours per day. For example, if the daily average electricity usage is 30 kWh, and the site is in Toronto, the system size would be:

Step 5: Determine the number of PV modules required for this system. Divide the system AC watts found in Step 4 by the CEC watt rating of the modules to be used, and then divide by the "inverter efficiency", usually 0.94, to obtain the total number of modules required. (Round up this number)

To calculate the solar water heater panel for the space heating and/or domestic hot water, the total heat demand plus the heat loss should be divided by the heat that each panel generates. The solar water panel for the cases is model WSE58. This heat collector panel is chosen from the WSE technology, being the Canadian manufacturer. WSE58 generates 2,741.3 kJ (2600 Btu/hr).

5. CASE STUDIES

Different buildings are considered as case studies for using renewable energy. Various energy options are measured; related emission reduction is assessed. These case studies are residential houses, with different energy consumption pattern.

The technologies for converting natural energy to useable energy are vacuumed solar water heaters, PV modules, and ground source heat pumps. Wind turbines are not practical technology for this thesis because all cases are in urban areas and according to bylaw 270-3004, wind turbines are not permitted to be installed. Besides vacuumed solar water heaters, PV modules and ground source heat pumps, some other hybrid systems, which are a combination of aforementioned renewable technologies, are designed to provide renewable energy resources for each case.

5.1. Case Study #1

Case study#1 is residential house in Brampton, Canada with latitude 43.536 and longitude -79.556. Case study #1 is a 4+1 bedroom detached house, with five residents. In this house, furnace works with natural gas and electricity; the heating system is forced air. The living area in house is almost 214 m^2. The energy consumption in this house is under control and saving energy is respected by the household.

The electricity consumption in the last year in this household was 5,506 kWh, the average daily consumption is 15 kWh, the highest daily rate is 18 kWh and the lowest daily rate is 12 kWh. The distribution of the electricity consumption in Case study #1 is categorized in Figure 1.

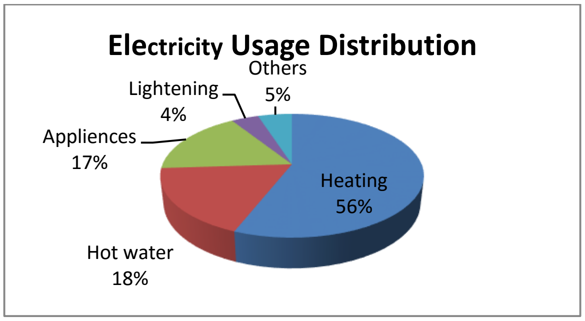

Figure 1 Electricity usage distribution for case study #1.

The natural gas consumption of this house is 2,760 m^3, and the average daily consumption of the natural gas comes to 7.5 m^3.

Available technologies for Case study #1 are as followed:

- solar thermal in form of vacuumed pipes for the domestic hot
- solar electric in form of PV panels for generating electricity
- geothermal system in form of ground source heat pump for heating and cooling.

Also, there are three types of hybrid systems:

- hybrid system #1 including geothermal system and solar electric for providing heating and cooling plus needed electricity for running the heat pump
- hybrid system #2 including solar thermal and solar electric to supply some electricity and hot water for the household
- hybrid system #3 including geothermal system and solar thermal to provide heating and cooling plus hot water for the household.

All these six scenarios are sized for Case study #1. The summary is in the Table 1. In the next step is to calculate the emission reduction for each scenario to find out the CO_2 elimination. The results of the CO_2 reduction are shown in Table 2.

5.2. Case Study #2

Case study #2 is another detached house in Oshawa, Ontario, latitude 43.696 and longitude -78.871. The specification of this house is almost the same as Case study #1, 4 bedrooms with five residents. In this house the furnace runs on natural gas, and the electricity and heating system are forced air as well. The living areas in these houses are approximately 215 m^2. The first floor consists of the kitchen, the living/dining room, the family room, and a bathroom; the second floor is made up of four bedrooms, and two bathrooms, and the basement is a full basement.

The main difference between Case study #1 and Case study #2 is the energy consumption pattern. Energy usage in Case study #2 is significantly higher than in Case study #1. Natural gas and electricity consumption are both noticeably higher than in Case study #1.

The electricity consumption in the last year in this household was 13,303 kWh, the average daily consumption is 36.4 kWh, and the highest daily rate would be 44 kWh

The distribution of energy consumption in Case study #2, as a regular household, is almost the same as in Case study #1. The natural gas consumption is 3,980 m^3; therefore, the average daily natural gas consumption for the Case study #2 household yields to 10.9 m^3.

Technologies for Case #2 are the same as Case #1, solar thermal, solar electric, and ground source heat pump. Also, there are hybrid system #1 including geothermal system and solar electric, hybrid system #2 including solar thermal and solar electric, and hybrid system #3 including the geothermal system and the solar thermal one.

All these six scenarios are sized for Case study #2. However, solar water heaters, geothermal system, hybrid system #1, and hybrid system 3 are the same as Case #1 and geothermal system is the same as the summary is in the Table 1. In the next step, the environmental protection for each scenario is calculated based on how much reduce CO_2 emissions. The results of the CO_2 reduction are shown in Table 2.

6. RESULTS AND DISCUSION

Two different cases are studied and sized for different renewable technologies including solar water heaters, PV modules, ground source heat pumps and different combinations of these technologies. Data results are analyzed based on technological views, environmental aspects.

6.1. Technologies Comparison

As all the cases are in urban areas, the most available and safe renewable technologies are chosen. These technologies are solar heater collectors, photovoltaic panels, and ground source heat pumps. Hybrid systems as a combination of two technologies are designed as well. For all cases, hybrid system #1 as a combination of geothermal technology and PV panels, hybrid system #2 as a combination of solar water heaters and PV modules, and hybrid system #3 as a combination of solar water heaters and ground source heat pump are obtained. Table 1 briefly depicts options of renewable technologies for each case study.

Along with prioritizing different energy options, the following facts are also considered.

- It is clear from Table 1 that the numbers of solar water heaters are much less for each case; the installation is cheaper for the solar water heaters when compared with the PV panels.
- Since the quantity of solar panels is larger, the space for the installation needs to be bigger.
- PV panels need to be tilted four times per year and must be cleaned after each snow. Therefore, PV panels require more maintenance.
- A geothermal system is the most reliable energy system, with special initial installation and low maintenance.

Table 1. Technology summaries for case studies.

		Residential	
		Case #1	*Case #2*
Technology	***Solar Heater Panels***	4 WSE58	4 WSE58
	PV Panels	22 x 215 W	56 x 210 W
	Geothermal system	GT049	GT049
	Hybrid System study #1	GT049 + 8 x 210 W	GT049 + 8 x 210 W
	Hybrid System study #2	4 WSE58+22 x 215 W	4 WSE58+56 x 210 W
	Hybrid System study #3	45 WSE58+GT049	45 WSE58+GT049

6.1.1. Case study #1 Technology Comparison

Case study #1 is the house with low energy consumption, and six different options of renewable sources of energy. Discussion about technologies for this case is based on two categories: solar energy technologies and geothermal energy.

6.1.1.1. Solar Energy Technology Comparison

Using solar heater panels is a good choice for heating domestic hot water in this residential building because they are easy to install and maintain. However, PV panels are a good source of electricity for Case study #1. Using both technologies, hybrid system study #2, will bring more savings to the household. As this house is in an urban neighborhood, it would be a better idea if a subdivision as a community runs sets of PV panels; in this way, maintenance is less of a burden on individuals. Furthermore, PV panels will have a designated area which is safe from any theft or damage by children’s balls.

6.1.1.2. Geothermal Energy and Solar Energy Comparison

When comparing geothermal energy and solar energy, ground source heat pumps are in first place, since they are a reliable source of energy and incredibly cost effective. For using solar technologies, either PV modules or evacuated heat pipes, there must be a backup system in place. The main approach for solar technologies is to store energy when the sun is available, and to use the energy when it is needed. Ground source heat pumps, on the other hand, provide energy continually without interruption, and geothermal energy is always available. Moreover, the space which geothermal units needs does not change the exterior of the building, and the geothermal system is very easy to maintain. However, the initial installation of the pipes in the ground is not a clean procedure.

6.1.1.3. Alternative Energy Options Comparison

Six systems defined as alternative sources of energy are used in Case study #1: solar water heaters technology to provide the hot water of the household, PV modules to generate the electricity of the household, a geothermal system to provide the heating and cooling system of the household, and finally different hybrid systems. Figure 1 shows the energy consumption distribution in Case study #1.

- As a first choice in technology field PV modules are the answer, which generate electricity for Case study #1. These panels are easy to install and can run any application with available electricity. The energy consumption reduction goal for this system is 100%.

- Hybrid system #3 (geothermal system + solar thermal) is the second choice from a technical aspect, since it is reliable to heat/cool space as well as providing domestic hot water in Case study #1. Besides, hybrid system #1 has a targeted reduction of energy consumption of the household of about 62.8% (1/5 X 56% by heating/cooling + 18% hot water).

- Hybrid system #1 (geothermal system + solar electricity) is the third choice by targeting 56% of energy consumption reduction through providing heating/cooling energy. In this fairly independent system, ground source heat pumps receive electricity by PV modules.

- Geothermal technology is the fourth choice because this technology is dependable and cost effective as a HVAC system. Target energy reduction for this system is 44.8% (4/5 X 56%).

- Hybrid system #2 (Solar Thermal + Solar Electricity) stands as the fifth choice by aiming for 44% energy reduction through providing domestic hot water and electricity.

The last, but not the least is for solar water heaters, which provide the hot water for the household. This system is very efficient and easy to maintain. Energy reduction target for this system is 18%.

Figure 2 depicts the summary of technology prioritization for Case study #1.

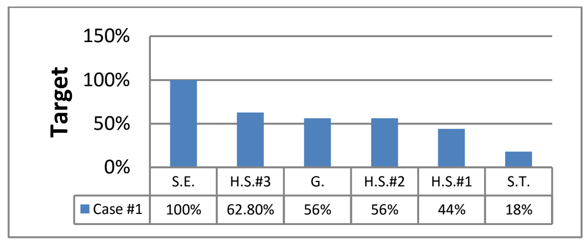

Figure 2. Prioritized options from technological point of view for Case study #1.

6.1.2. Case study #2 Technology Comparison

Case study #2 is the house with high energy usage. The energy consumption in Case study #2 is almost twice that of Case study #1. It is strongly recommended that this household, prior to starting any renewable energy project, start changing its energy consumption pattern. By cutting the extra energy usage, the demand for PV panels will be smaller, thereby shrinking the cost.

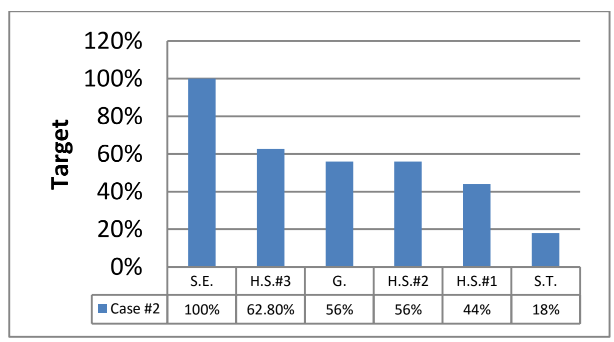

Figure 3. Prioritized options from technological point of view for Case study #2.

As the distribution of energy consumption is almost the same as in Case study #1 (Figure1 is applicable to Case study #2), and renewable energy technologies applicable to Case study #2 are very similar to Case study #1, the technology discussion in section 6.1.1 is applicable for Case study #2 as well. Figure 3 illustrates the summary of prioritization of the technology for Case study #2.

6.2. Environmental Comparison

The detailed calculation for solar heater panels, PV panels, and geothermal technology and hybrid systems for each of the four cases has been done in the previous chapter. The positive effect of each technology on the environment by preventing emission in CO_2 has been calculated. The environmental supportive effects on each technology and each case are summarized in Table 2.

Table 2. Environmental effect summaries.

		Residential	
		Case #1	*Case #2*
Emission Reduction (kg CO2)	***Solar Heater Panels***	1161	1161
	PV Panels	1581	3892
	Geothermal sys.	3150	3150
	Hybrid System study #1	3466	3466
	Hybrid System study #2	2741	5053
	Hybrid System study #3	4311	43121

The effects of different technologies on eliminating CO_2 for each case study are listed in Table 2. However, for each case study, more than one project can be run. For example, for Case study #2, solar water heaters and PV panels can be installed without any interference. By using both technologies, CO_2 would be reduced drastically; however, if prioritizing the technologies is the case, then overall from Table 2, PV panels protect the environment slightly more than solar water collectors. And even geothermal is a better protector from the environment. By using two technologies, hybrid systems maximize the environmental guard.

6.2.1. Case study #1 Environmental Comparison

In this residential house, hybrid system study #3 (Solar Thermal and Geothermal) reduces the maximum CO_2 emissions by 4311 CO_2 /year. Hybrid system #1 protects the environment by 3466 kg CO_2/year, so this design, which is a combination of geothermal technology and PV modules, stands in second place. Third place is for geothermal technology with a reduction of 3150 kg CO_2/year. Hybrid system #2 by a reduction of 2741 CO_2/year is in fourth place. PV modules, with protection of 1582 CO_2/year, stand in fifth place. By using four solar heater panels, the environment is protected by 1,161 kg CO_2/year. Evacuated tubes are the last choice. Figure 4 illustrates the summary of environmental protection prioritization for Case study #1.

6.2.2. Case study #2 Environmental Comparison

In Case study #2, the residential house with high energy consumption, for prioritizing renewable energy technologies from the point of environmental protection, hybrid system #2 (Solar Thermal & PV modules) with 5053 CO_2/year would be the first choice. Second place is reserved for hybrid system #3 (Solar Thermal & geothermal) by protecting the environment by 4311 CO_2/year. Hybrid system study #1 (Geothermal & PV modules) is the third choice of technology by saving nature from 3466 CO_2/year. Fourth choice is PV modules - using 56 photovoltaic panels, the environment will be protected from 3,892 kg CO_2/year. Ground source heat pumps stand in fifth place by 3150 CO_2/year. The last choice would be evacuated pipes which save the environment from 1,161 kg CO_2/year, by using four solar collector panels. However, as suggested, by making some changes around the house to increase energy efficiency, the environment will also be protected by reducing energy consumption. Figure 5 depicts the summary of environmental protection prioritization for Case study #2.

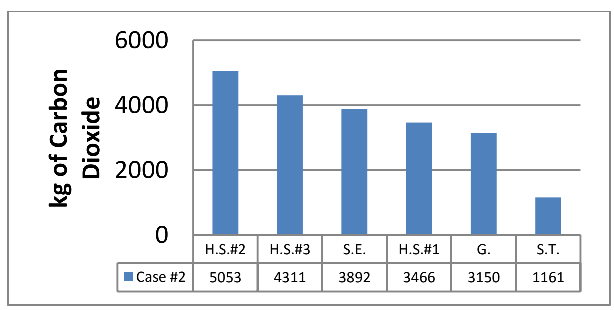

Figure 4. Prioritized options from environmental point of view for Case study #1

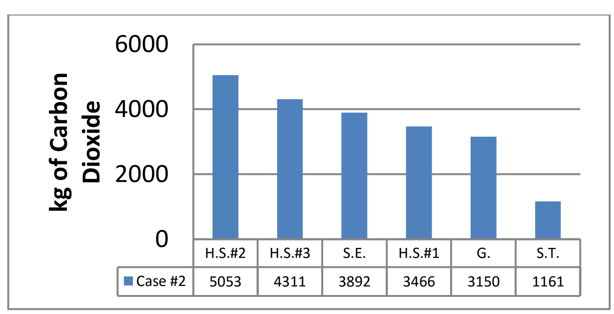

Figure 5, Prioritized options from environmental point of view for Case study #2

7. CONCLUSIONS

The results obtained show that hybrid systems are the best choice if target is to reduce CO_2 emission. In contrast, when decision making is based on budget then hybrid systems are the last choice since they are combination of two systems and being more costly. Prioritizing on technology for the residential building by considering energy consumption pattern is first the PV panels, then hybrid system #3, ground source heat pump, hybrid system #2, hybrid system #1, and finally solar water heaters. Technology, environmental protection and cost are not only the main factors to decide on renewable technologies, but also are the reliability, installation, maintenance and ease of use. One can conclude to say:

- Solar thermal technology is an efficient technology for heating space and domestic hot water, with the lowest initial cost, easy for installation, and low in maintenance.
- Photovoltaic modules are a practical technology to provide electricity, and also high in maintenance.
- Ground source heat pump is a reliable renewable technology with highest possible efficiency but complicated installation.
- Hybrid Systems are holding advantages of two renewable technology systems but are costly.

The final decision absolutely depends on owners or management's budget and mentality in each case. However, using energy smartly and eliminating energy waste is always recommended. It is saving money and protecting the environment from harmful emissions.

REFERENCES

Alert idea's website, 2009 www.alertidea.com

Dincer, I., Kanoglu, M., Rosen M.A., 2008 Role of exergy in increasing efficiency and sustainability and reducing environmental impact, Energy Policy; 36: 128-37.

Dincer, I., Midilli, A., 2007 Key Strategies of hydrogen energy systems for sustainability, International Journal of Hydrogen Energy 32(d): 511-24.

Dincer, I., Midilli, A., 2008 Hydrogen as a renewable and sustainable solution in reducing global fossil fuel consumption, International Journal of Hydrogen Energy 33: 4209-4222.

Hartly, D.L., 1990 Perspectives on renewable energy and the environment, In: Tester, J.W., Wood, D.O., Ferrari, N.A., editors. Energy and the Environment in the 21st century, Massachusetts: MIT.

IPCC, 2001 Climate change 2001: The scientific Basis, Cambridge University Press, Cambridge.

McGowan J.G., 1990 Large-scale solar/ wind electrical production systems-predictions for the 21st century, Massachusetts: MIT.

Strong, M.F., 1992 Energy, environment and development, Energy Policy 20: 490-4.

BIOGRAPHY

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